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FINAL REPORT

PROJECT 5153-33819

DETECTION OF AMBLYOPIA UTILIZING
GENERATED RETINAL REFLEXES

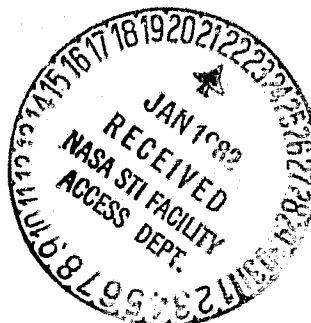
J. H. KERR, S. H. HAY

CONTRACT NAS8-33819

Prepared for
NATIONAL AERONAUTICS & SPACE ADMINISTRATION
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13 November 1981



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ABSTRACT

This report summarizes the research and development performed under contract NAS8-33819. The objective of the research and development was to evaluate the concept of using generated retinal reflex (GRR) images to detect the antecedents of amblyopia. The investigations confirmed that GRR images can be consistently obtained, furthermore these images contain information required to detect the antecedents of amblyopia; eg., optical inequality of one eye compared to the fellow eye.

Digital analyses, electro-optical analyses, and trained observers were used to evaluate the GRR images. Even though several digital algorithms and electro-optical techniques were tried, no objective evaluation method was found.

Two and three dimensional plots were made from the digital analyses results. These plotted data greatly enhanced the GRR image content, and it was possible for non-trained observers to correctly identify normal vs abnormal ocular status by viewing the plots.

Electro-optical evaluation techniques which were used in this program did not provide satisfactory results because they could not resolve subtle differences in ocular inequality.

Based upon the criteria of detecting equality or inequality of ocular status of a person's eyes, the trained observer correctly identified the ocular status of 90% of the 232 persons who participated in this program.

PREFACE

This report summarizes work performed under contract NAS8-33819 during the period May 13, 1980 through November 13, 1981. It is the culmination of a study of the detection of amblyopia using generated retinal reflexes, and represents the final report on the research program authorized under contract NAS8-33819. This program was conducted under the technical cognizance of Dr. R. R. Jayroe, Jr.; code E F-36, and Mr. J. R. Richardson; code AT-01, of the Marshall Space Flight Center. Their interest throughout this study is gratefully acknowledged.

Furthermore, the authors acknowledge and appreciate the contributions of Dr. Robert McBride, and Ms. Pat Bowman of the Alabama School of the Deaf, Talladega, Alabama. Their tireless efforts and gracious hospitality made it possible to pleaurably acheive a successful completion of the contract's Exhibit B scope of work.

1.0 INTRODUCTION

Contract NAS8-33819, entitled, 'Detection of Amblyopia Utilizing Generated Retinal Reflexes', was begun 13 May 1980 and continued through 13 November 1981. The effort was jointly funded by the National Aeronautics and Space Administration (NASA), and Electro-Optics Consultants, Inc., (EOC). The purpose of the contract was to determine the feasibility of utilizing NASA technology in the development of a low cost ocular screening system which generates, records, and analyzes retinal reflexes to determine the ocular status of a person's eyes.

With the exception of section 2.0, this report covers the work performed and the results obtained during the period of the contract. Section 2.0 contains information obtained from EOC's previous investigations of generated retinal reflex photometry. This section is included to provide a background for the work described in this report.

The contract's scope of work encompassed several tasks. Since the contract was jointly funded, personnel from Marshall Space Flight Center's (MSFC) Data Systems Laboratory and Technology Utilization Office assisted EOC in performing the activities required to complete the tasks which required: the digital analyses of spectrum and retinal reflex images, the marketing plan for an ocular screening device, and the generation of a retinal reflex data base.

Specifically, MSFC's personnel operated the digital equipment and provided EOC with the results, obtained a marketing survey for the ocular screening device and gave EOC copies of the survey report, and negotiated with the director of the Alabama School for the Deaf (ASD) in Talladega, Alabama and obtained permission to photograph ASD's students to provide a generated retinal reflex data base.

The remainder of the tasks were performed by EOC personnel under the technical cognizance of the contracting officer's representative. These tasks included the design and fabrication of a spectrograph used to obtain the spectrum images; design, fabrication, and delivery of a generated retinal reflex photometer to ASD; designed, fabricated, and evaluated a low resolution image analyzer (LRIA); and developed a marketing plan for an ocular screening device.

Appendix A of this report contains a description of the LRIA.

Appendix B contains a paper which S. H. Hay, M.D, will present at the Southern Medical Association Conference in New Orleans, Louisiana, during the week of November 15-19, 1981. Subsequently, it will appear in the proceedings of the Southern Medical Association which will be published following the conference.

2.0 BACKGROUND

Generated retinal reflex photometry is a method for recording the image of the retinal reflex from a person's eyes under simple, but special, conditions. The process is completely non-invasive and the results depend solely on the analysis of the recorded image. The photograph of the retinal reflexes is analyzed by quantifying the intensity, spectra, and optical patterns of one reflex, and then comparing these results with the same characteristics of the fellow eye, or an idealized normal eye. Careful analysis of the retinal reflex not only isolates amblyopic and pre-amblyopic conditions, but it may also detect a variety of pathological conditions of the ocular system.

Prior to the contractual arrangement with NASA, EOC and its associates had demonstrated the feasibility of detecting ocular abnormalities in humans by manually evaluating the intensity, spectrum, and pattern characteristics of their generated retinal reflex images. Manual evaluation of the images involved projecting the images onto a screen, and having a trained observer make a subjective evaluation of the person's ocular status. Even though the generated retinal reflex photometer provided retinal reflex images which were used to demonstrate feasibility, the photometer could not provide repeatable images representative of a person's retinal reflexes.

Table 2.1 lists the discrepancies observed in the images, and their causes. To alleviate the problems associated with the generated retinal reflex images, the photometer was repackaged and mounted on a tripod. battery powered electronic flash system was replaced with a more powerful electronic flash. The new flash was located to eliminate a vignetting problem. The 50 millimeter lens was replaced with a 100 millimeter lens to reduce the field of view. These modifications to the photometer greatly improved its performance, but the generated retinal reflex image failure rate remained above fifty percent.

Table 2.1

IMAGE PROBLEMS

| DISCREPANCY | CAUSE |
|--|--|
| <ul style="list-style-type: none"> o Non-uniform illumination of both retinas o Images not properly focused o Inadequate image contrast o Under exposed negatives o Retinal reflex images were too small o Field of view was too large o Partial retinal reflexes | <ul style="list-style-type: none"> o Inability to maintain the proper optical angular alignment between the photometer and person being photographed o Person moved after the camera had been focused, and before the photograph was taken; or photometer was jarred and moved from its original position o Battery discharge, and non-uniform light distribution from the flash o Insufficient illumination from electronic flash o Insufficient lens focal length, or subject was too far away from the photometer o Insufficient lens focal length o Flash unit vignetting the lens system |

3.0 SPECTRAL DATA

Spectrograms were required to calibrate the image digitizer equipment; and after calibration, to digitize and extract spectral information from generated retinal reflex images.

3.1 SPECTROGRAPH PACKAGING CONCEPT

At the inception of the contract, a spectrograph was fabricated based upon the assumption that the low level intensity of the generated retinal reflexes would generate a spectrum of sufficient intensity to expose high speed film. Low speed film coupled with appropriate camera settings would be used to obtain spectrograms of high intensity light sources.

Figure 3.1 depicts the layout of the spectrograph. To obtain the maximum flux density, an input lens was used to focus the light energy on a variable width slit. The slit was imaged on a diffraction grating by an acromatic lens (not shown). Light which passed through the linear diffraction grating was made incident upon a photographic film located in the 35 millimeter camera back. The diffraction grating and camera back were aligned such that the target source and the positive first order spectral components were recorded on the film.

3.2 SPECTROGRAPH LIGHT SOURCES

3.2.1 MERCURY ARC LAMP

A mercury arc lamp source was used to make the calibration spectrograms. Strong, distinct spectral lines were obtained.

3.2.2 GENERATED RETINAL REFLEXES

The light energy from generated retinal reflexes was found to be insufficient to expose the highest speed film which was commercially available. Therefore, spectrograms of the generated retinal reflex images were made by

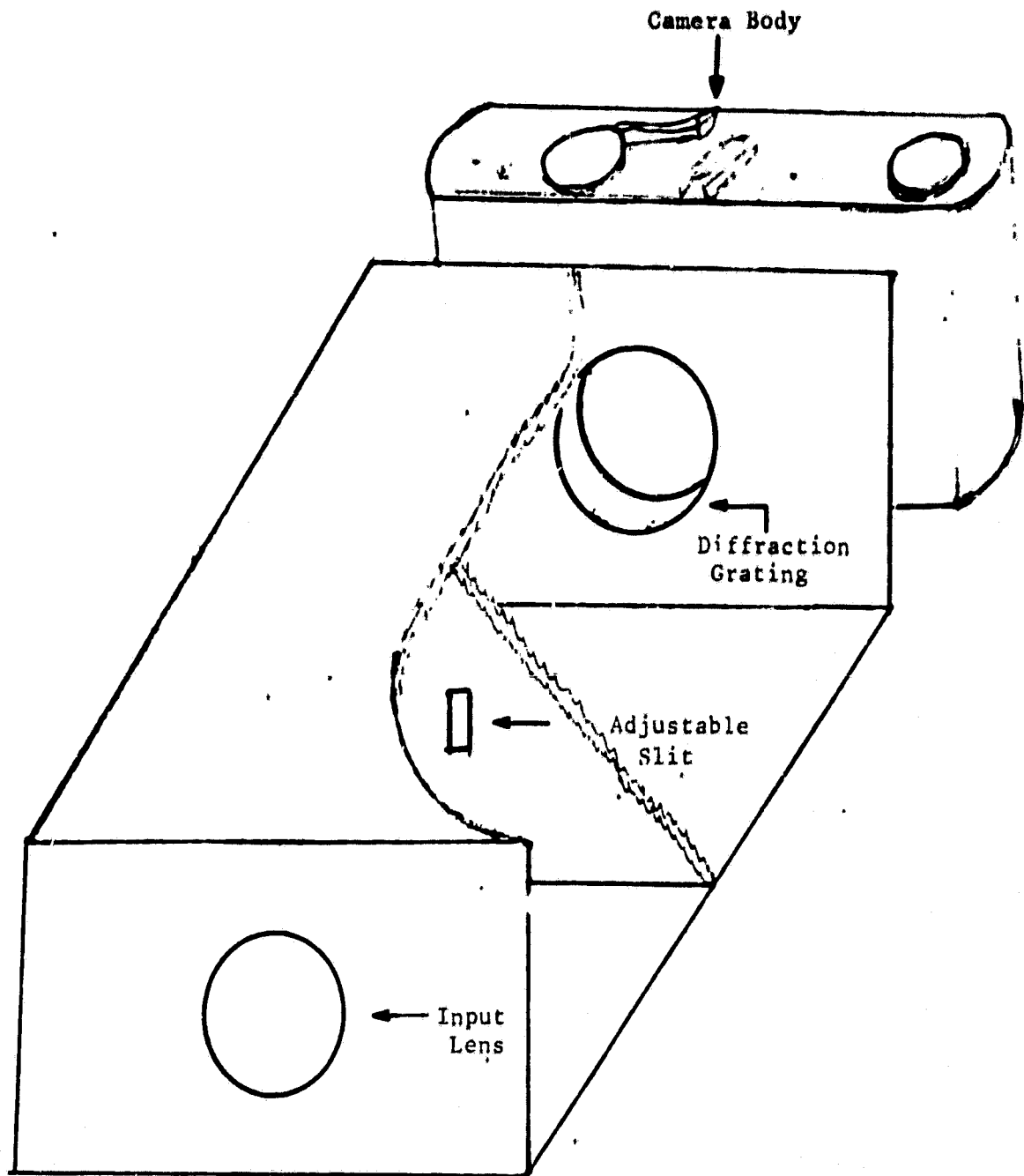


Figure 3.1 SPECTROGRAPH

illuminating generated retinal reflex images which had been recorded on 35 millimeter transparencies. The illuminating source was a xenon flash which was synchronized with the spectrograph's shutter. This method of obtaining retinal reflex spectral data proved to be undesirable because it introduced errors related to film development processes, flash non-linearities, and a host of other perturbations.

3.3 LABORATORY SET-UP AND ALIGNMENT

The mercury arc lamp, Oriel model 6301, was mounted on a stable optical table three (3) meters in front of the spectrograph's collecting lens. The intensity was adjusted to obtain an image of the source illuminated slit, and three orders of the mercury lines. The spectrograph's camera, a 35 millimeter single lens reflex (SLR), was positioned such that only the image of the slit and the first order spectrum were within the field of view.

Spectrograms were recorded on Kodak Tri-X film using exposure times ranging from one (1) millisecond to seventy five (75) seconds. These spectrograms were developed and the negative images were evaluated at the MSFC's Data Systems Laboratory computer facility.

3.3.1 SPECTROGRAM ANALYSES

The digitizer used to extract the spectral data from the spectrograms was adjusted to mechanically scan the spectrograms and obtain a reading every 17.5 microns. The ideal situation existed only when the scanner head was located at the centroid of the exposed spectral line. Since the centroid was subjectively estimated, several lines with different slopes were obtained from the spectrograms. Regression analysis techniques were used to obtain a linear prediction equation that best fit the set of spectrogram data.

Equation 3.1 resulted from the regression analysis.

$$\lambda = 4.95d + 98.98 \quad \text{eq. 3.1}$$

Where: λ = wavelength of spectral line

$$d = (X^2 + Y^2)^{\frac{1}{2}}$$

X = number of columns the scanning head moved to go from the centroid of the slit image to the centroid of the spectral line.

Y = number of rows the scanning head moved to go from the centroid of the slit image to the centroid of the spectral line.

Figure 3.2 shows a plot of wavelength vs distance obtained from the analysis of the mercury arc lamp's spectrogram. Equation 3.1 compared very closely to results obtained from optical measurements of the spectrogram. Therefore, the equation was used as the calibration equation for the image digitizer when it digitized spectrograms made during this program.

3.3.2 PHOTOMETER FLASH SPECTRUM

To obtain spectrum data from generated retinal reflexes, a flash system must have a constant spectrum over the bandwidth of 4000 to 7000 angstroms. Therefore, a spectrogram was made of the xenon flash used in this program.

The spectral content was evaluated by the image digitizer after the calibration equation had been determined. Figure 3.3 shows the spectral content and the intensity of the flash source. As shown in the figure, the xenon flash covered the required bandwidth and the intensity was relatively constant across this bandwidth. The xenon source's spectral source wavelength cutoff was caused by the high end cutoff characteristics of the film.

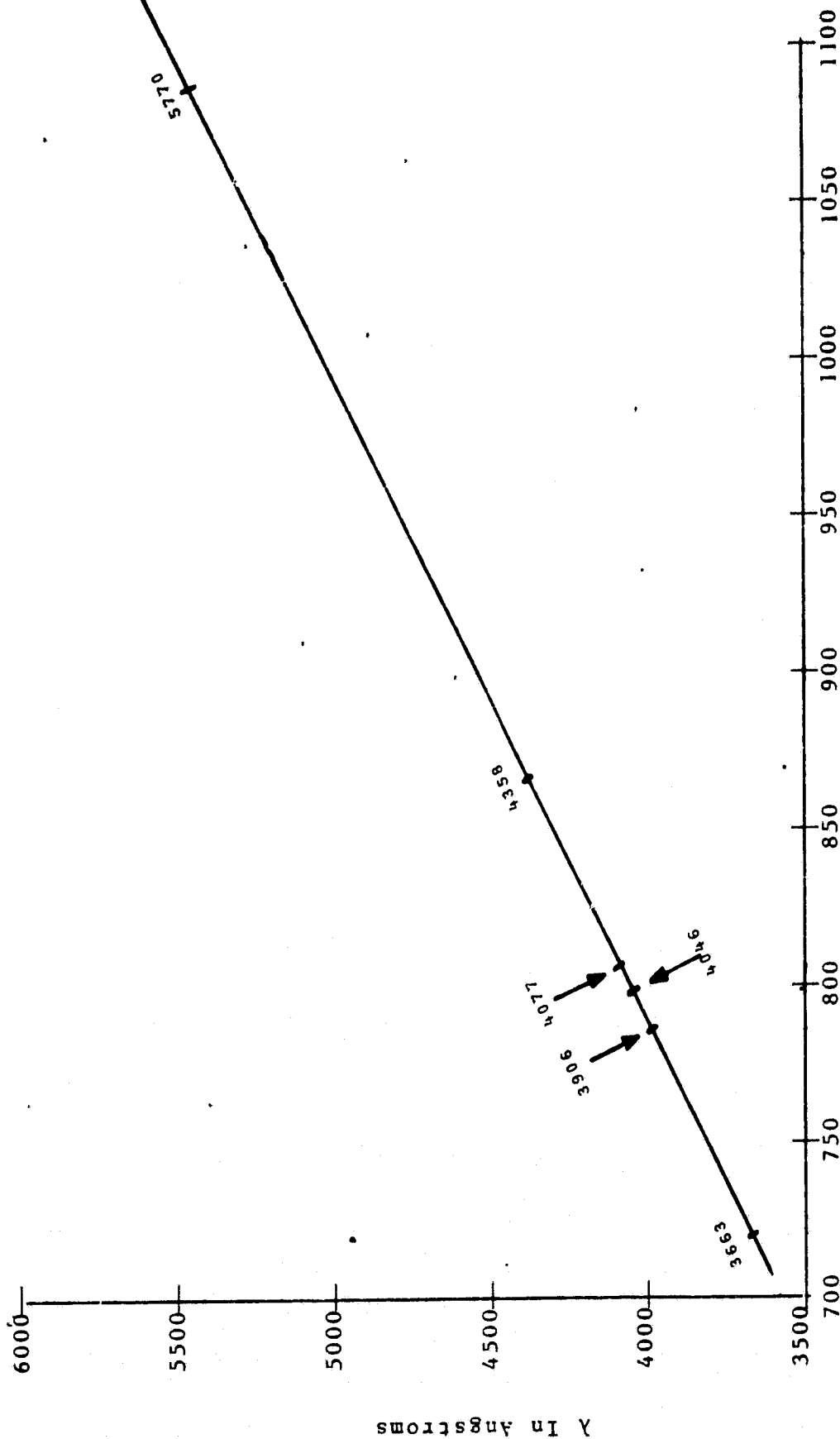


Figure 3.2 MERCURY ARC LAMP SPECTRUM

d In Microns
Digitized At 17.5 Micron Spot Size

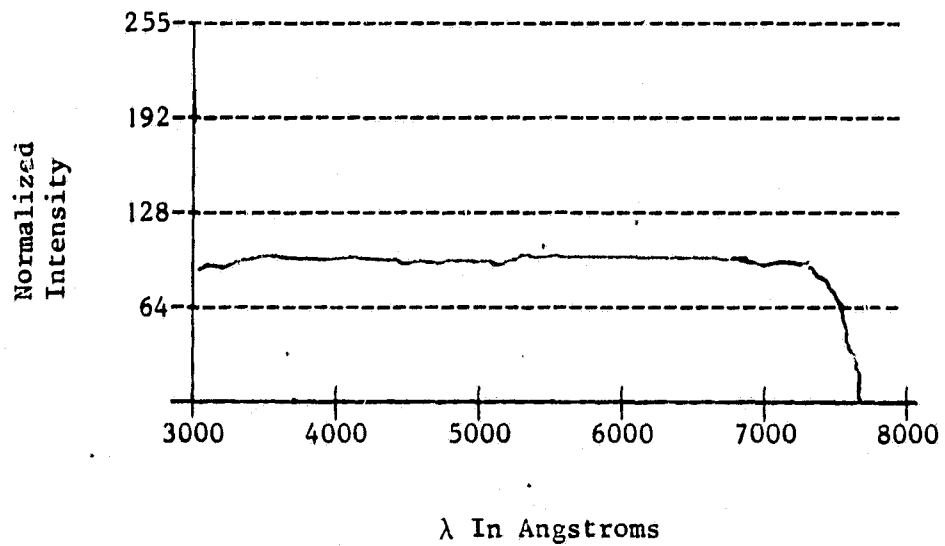
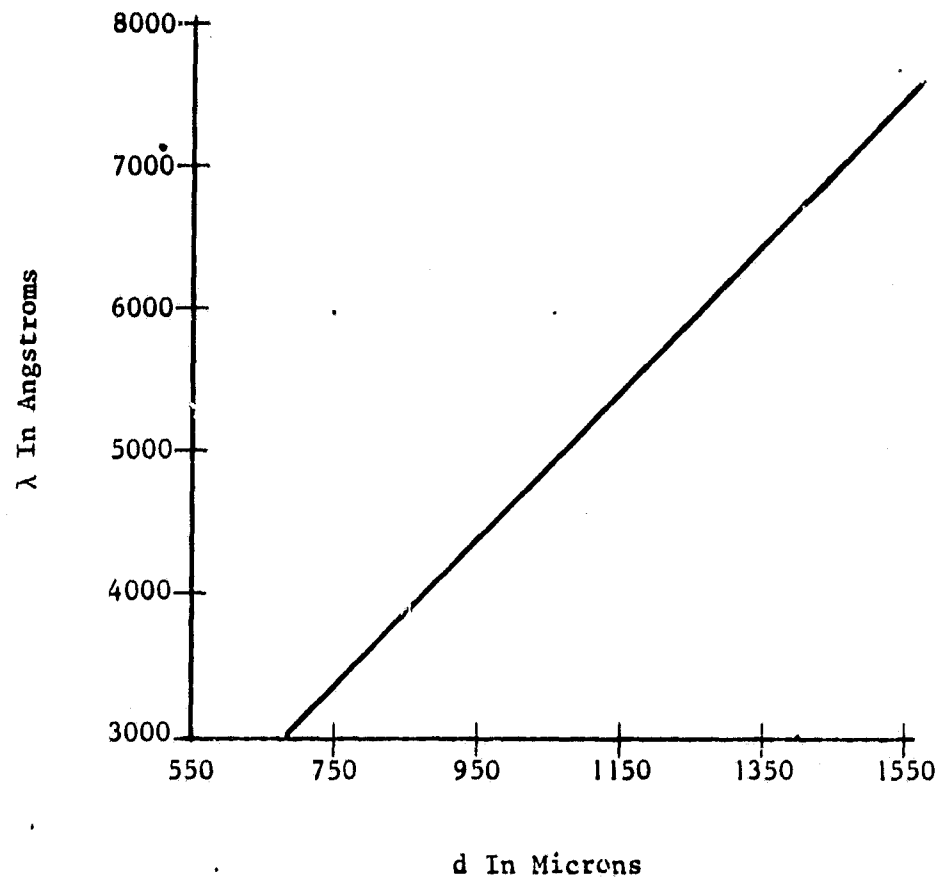


Figure 3.3 RESULTS OF DIGITIZED ANALYSES OF THE XENON FLASH SOURCE

4.0 GENERATED RETINAL REFLEX PHOTOMETRY

Initial investigations conducted under this contract revealed that the modified photometer described in section 2.0 was not adequate for use in this program. Therefore, a photographic system was designed and fabricated to eliminate the inconsistency of obtaining retinal reflexes. Once the newly designed system became operational, obtaining quality retinal reflex images was no longer a problem, and the system generated and recorded all retinal reflex images for the remainder of the program. During the design and fabrication of the photographic system emphasis was placed not only on selecting and packaging the components for ruggedness, but also heavy emphasis was placed upon accurate alignment between the photometer and the person being photographed.

4.1 PHOTOGRAPHIC SYSTEM

The photographic system contained two stations which were located 5.76 meters, (18.9 feet) apart. Station one held the photometer, and provided a work area for the photographer. Station two provided a screen to mask out all of the person's body except a six (6) by twelve (12) centimeter area which included both eyes. The screen contained numbers which identified the person. When the person was photographed, the person's eyes and identification numbers filled most of the image area.

The two stations were aligned such that the photometer's line of sight was perpendicular to the person's eyes. This alignment assured that both eyes received the same amount of input intensity. The 5.6 meter distance was chosen because it exceeded the distance required to achieve optical infinity of the average person's ocular system. Therefore, the focus of a person's eyes was not a variable that had to be considered in the retinal reflex image analyses process.

4.2 PHOTOMETER

Figure 4.1 is an isometric drawing of the photometer used in this program.

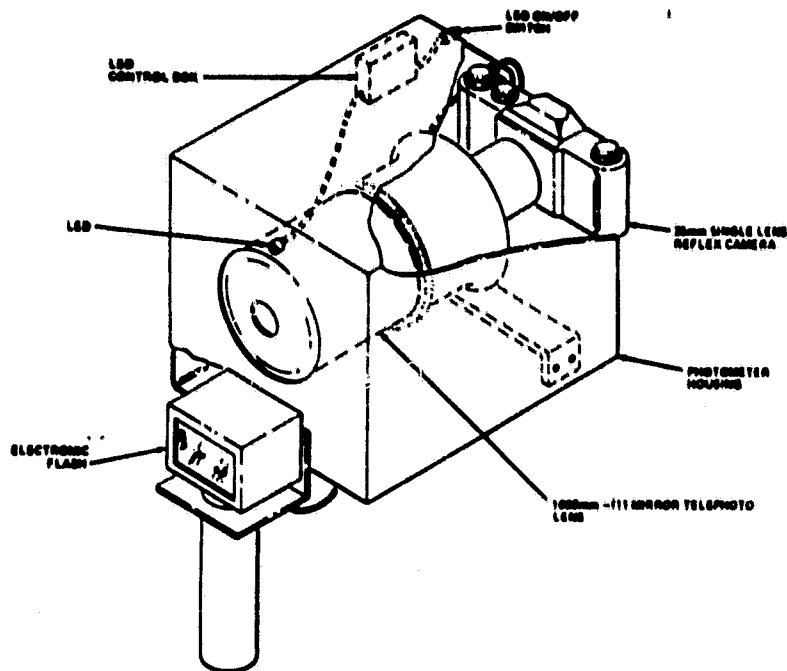


Figure 4.1 GENERATED RETINAL REFLEX PHOTOMETER

Light energy which produced the generated retinal reflexes was provided by a Sunburst Model 611 electronic flash. The flash unit was located such that the vector which defined the centroid of the emitted light was offset .6 degrees from the photometer's optical line of sight.

The 35 millimeter camera body, was modified to accept a one meter, F-11, Cassegrain mirror telephoto lens optics. The lens's field of view at station two was approximately .3 meters, and the depth of field at station two was approximately 16 millimeters. Therefore, the data contained on the exposed film was limited to the person's eyes, bridge of the nose, eyebrow portion of the forehead, and their identification number.

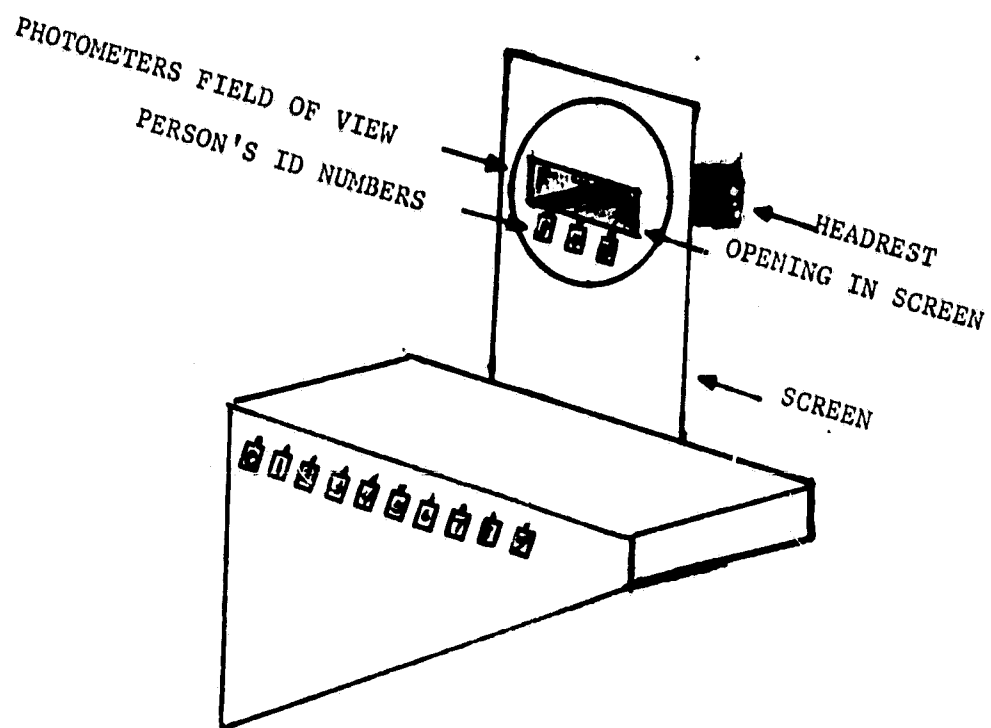
The light emitting diode (LED) located above the telephoto's lens blinked at a ten pulse per second rate. The diode provided a visible target on which a person could fixate their eyes.

4.2.1 FILM AND PROCESSING

The film used in this program was Kodak Ektachrome, ASA 400. It was developed and processed by Kodak.

4.2.2 STATION NUMBER 2

Figure 4.2 shows an isometric drawing of station 2. The person to be photographed was placed behind the screen, after their identification numbers had been placed below the opening in the screen. They placed their faces in the headrest such that their eyes were within the camera's field of view from station 1. The circle, containing the opening in the screen and the person's identification numbers, represents the camera's field of view.



STATION 2-LOCATION OF PERSON BEING PHOTOGRAPHED

Figure 4.2 ISOMETRIC DRAWING OF STATION NUMBER 2

5.0 GENERATED RETINAL REFLEX IMAGES

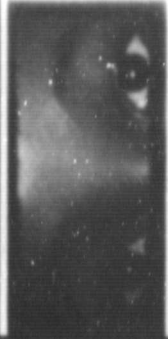
A total of two hundred seventy two retinal reflex images were obtained with the photographic system described in section 4.0. The following two pages contain color reproductions of sixteen sets of generated retinal reflex images.

The photograph which contains ten sets of images illustrates the intensity range of the generated retinal reflex images. Image intensity obtained from colored people with normal eyesight covered a large dynamic range. The dynamic range of white people with normal eyesight is relatively small.

The photograph which contains six sets of images illustrates persons who have abnormal eyesight. The persons, identification numbers 044 and 052, have one eye with normal eyesight and one eye with abnormal eyesight. Person number 044 is far sighted in the left eye. This condition is identifiable in the photograph by the light color at the top of the left eye's retinal reflex. Person number 052 has a light color rim at the bottom of the left eye's retinal reflex. This condition defines near sightedness. The four remaining persons have abnormal eyesight in both eyes.

It was observed that eyesight abnormalities in colored people showed up in the generated retinal reflex images as a lighter color, in many cases as almost white; whereas, the abnormalities in white people's eyesight showed up in the generated retinal reflex images as shades of predominately orange and yellow. The size of the color differences did not necessarily indicate the degree of abnormality when compared with visual acuity. This can be seen by comparing the nearsightedness of number 144 with the nearsightedness of number 141, and then observing the differences in visual acuity. Number 141 has a large area of color difference in both eyes, but his visual acuity is moderately abnormal. Number 144 has a small area of color difference, but his visual acuity is abnormal to the point of approaching legal blindness.

RACE-BLACK



JEL
SEX - MALE
HT - 17
WA - UNCORRECTED
DOB 2020



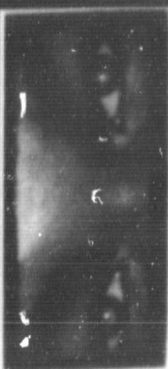
JEL
SEX - MALE
HT - 17
WA - UNCORRECTED
DOB 2020



JEL
SEX - MALE
HT - 17
WA - UNCORRECTED
DOB 2020

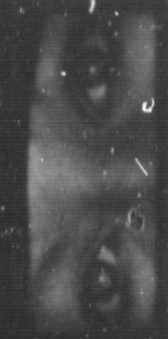


JEL
SEX - MALE
HT - 17
WA - UNCORRECTED
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JEL
SEX - MALE
HT - 17
WA - UNCORRECTED
DOB 2020

ORIGINAL PAGE
COLOR PHOTOGRAPH



JEL
SEX - MALE
HT - 17
WA - UNCORRECTED
DOB 2020



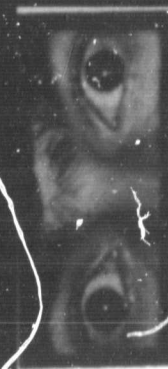
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SEX - MALE
HT - 17
WA - UNCORRECTED
DOB 2020



JEL
SEX - MALE
HT - 17
WA - UNCORRECTED
DOB 2020

ORIGINAL PAGE
COLOR PHOTOGRAPH

RACE-WHITE

ORIGINAL PAGE
COLOR PHOTOGRAPH

144

RACE - WHITE

SEX - MALE

RT LT
20/200 20/200

VA UNCORRECTED



052

RACE - WHITE

SEX - FEMALE

RT LT
20/20 20/50

VA UNCORRECTED



044

RACE - WHITE

SEX - FEMALE

RT LT
20/20 20+0

VA UNCORRECTED



132

RACE - WHITE

SEX - MALE

RT LT
20/25

VA UNCORRECTED

CATARACT IN LT EYE

RUBELLA



048

RACE - WHITE

SEX - MALE

RT LT
20/20 20/20

VA UNCORRECTED

PREMATURE



141

RACE - BLACK

SEX - FEMALE

RT LT
20/40 20/100

VA UNCORRECTED



5.1 ANALYSES OF GENERATED RETINAL REFLEX IMAGES

Three methods were used to analyze and evaluate the retinal reflex data.

These methods were:

- o digital analyses
- o low resolution image analyzer (LRIA)
- o trained observers.

The digital analyses techniques and trained observers utilized the image's intensity, spectral, and pattern characteristics. The LRIA analyses was restricted to the image's intensity.

5.2 DIGITAL ANALYSES RESULTS

Information contained in the retinal reflex images was digitally extracted by scanning the images with several different pixel sizes. The intensity of the pixel area was converted into an eight bit digital grey scale. This digital bit stream was fed to a digital computer where it was processed by several computer algorithms which had been developed to analyze Earth resources data taken by orbiting satellites. The output of the digital computer was plotted in both two and three dimensions. An example of the plotted data is shown in figure 5.1. In this example, the person had a cataract in the upper right portion on the right eye. The left eye had normal vision.

The depression in the three dimensional plot of the right eye indicates the decreased intensity in the area of the cataract. Correspondingly, the two dimensional plot shows that the intensity of the retinal reflex in the area of the cataract is less than the intensity of the surrounding area, and the intensity distribution is random. The left eye's three dimensional plot is relatively flat except for the peak which is caused by the high intensity of the corneal reflex. Correspondingly, the two dimensional plot of the left eye's retinal reflex image shows a pseudo-symmetrical pattern of the intensity distribution.

Two and three dimensional plots were made of thirty five pairs of retinal reflex images. It was demonstrated that a normal eye exhibited the characteristics of the left eye's plot in figure 5.1. Evaluating the plots of the retinal reflexes permitted an observer to correctly determine if the person's eyes were optically different.

Plots of the digital data clearly demonstrated that optical inequality could be detected from the generated retinal reflex images. While this method of evaluation provided excellent results, it was a time consuming and expensive method of analyzing the images because each plot required over two hours to complete. Since one of the program requirements was to evaluate techniques and select those which would lead to an inexpensive ocular screening procedure, the digital plot method was eliminated as a viably candidate for analyzing the images.

5.2.1 DIGITAL SPECTRAL ANALYSES

To obtain spectral characteristics of the images, a set of red, blue, and green bandpass filters were placed in the digitizer scanner mechanism. Light intensity passing through these filters was digitized and processed exactly as described in section 5.2. The spectrum analyses did not significantly add to the information obtained without spectral filtering. Therefore, spectral information was no longer extracted from the images.

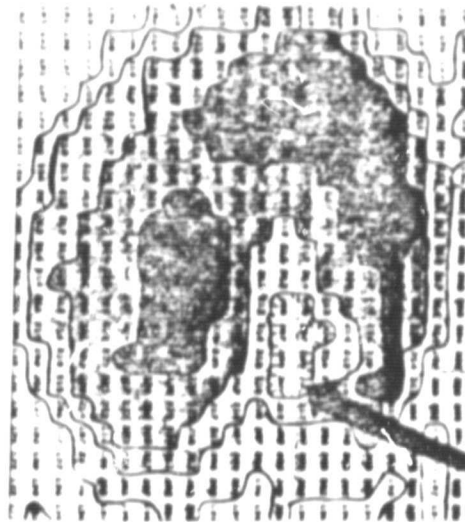
It was noted that if disease processes were to be determined, then spectrum could be a key characteristic of the image content.

5.2.2 PATTERN RESULTS

Information from the image pattern is obtained when either intensity or spectrum is plotted. Near sightedness and far sightedness is indicated by the position of the color or intensity variations in the generated retinal reflex images. Pattern information is required before accurate ocular screening can

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OF POOR QUALITY

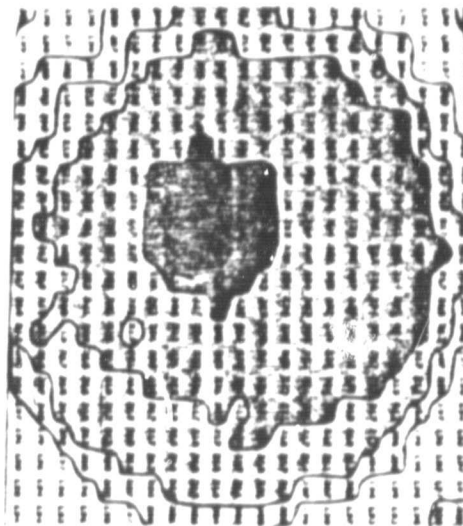
Right Eye



CATARACT



Left Eye



NORMAL EYE

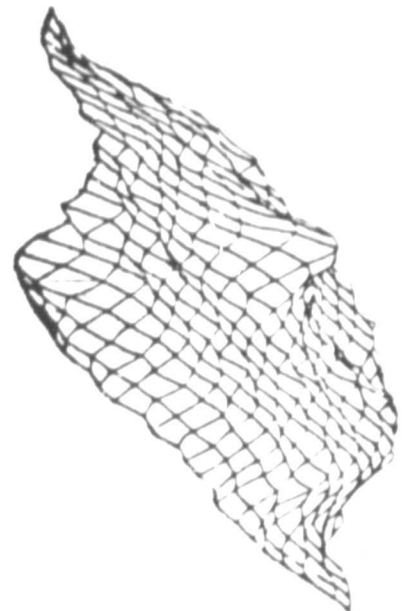


FIGURE 3.1 TWO AND THREE DIMENSIONAL PLOTS OF GENERATED RETINAL REFLEX IMAGES

be performed.

5.2.3 DIGITAL QUADRANT ANALYSES AND RESULTS

This analysis technique involved segmenting and identifying the retinal reflex image as indicated in figure 5.2, and then digitizing and analyzing each individual numbered segment as if it were a total image. Results of these analyses provided four distinct sets of information for each retinal reflex.

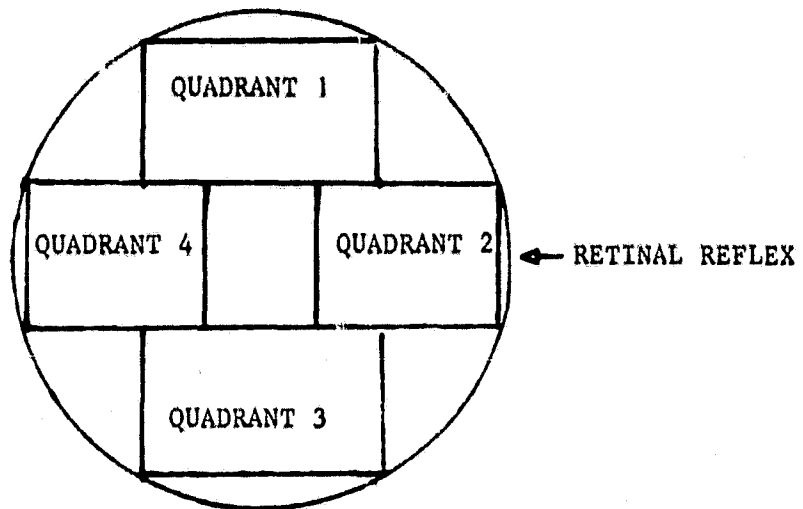


Figure 5.2 RETINAL REFLEX SEGMENTATION

While this technique enabled the evaluator to detect differences in the segments intensity, it required more time to digitize and process the information than did the procedure described in section 5.2. Only eight sets of retinal reflex images were evaluated in this manner; however, the process indicated that nearsightedness and farsightedness could be accurately determined based upon the intensity differences between quadrants one and three.

Figure 5.3 shows the results obtained from quadrant analyses of the retinal reflex images of person number 144. The results are typical of the eight sets of retinal reflex images analyzed. The maximum, minimum, and

Refer to Colored Photograph - Person Number 144

| | <u>RIGHT EYE</u> | | | | <u>LEFT EYE</u> | | |
|------------|------------------|------------|------------|------------|-----------------|------------|------------|
| | MAX. VALUE | MIN. VALUE | MEAN VALUE | | MAX. VALUE | MIN. VALUE | MEAN VALUE |
| QUADRANT 1 | 225 | 196 | 217 | QUADRANT 1 | 226 | 199 | 218 |
| QUADRANT 2 | 232 | 219 | 225 | QUADRANT 2 | 230 | 215 | 224 |
| QUADRANT 3 | 240 | 230 | 235 | QUADRANT 3 | 241 | 227 | 234 |
| QUADRANT 4 | 231 | 218 | 224 | QUADRANT 4 | 231 | 216 | 223 |

Figure 5.3 QUADRANT ANALYSES RESULTS - PERSON NUMBER 144

mean intensity values are given for each quadrant. Since quadrant three contains the highest mean value, nearsightedness is indicated. The mean value of quadrants two and four are equal within the accuracy of the digitizer; therefore, the person's status in these quadrants are considered to be equal, but undertermined.

This digital technique provided a degree of pattern information without plotting the data in two or three dimensions. Too, this technique can be implemented optically by modifying the low resolution image analyzer's electronic circuitry and adding a beamsplitter and two cylindrical lens to the iris and lens assembly. For LRIA description see appendix A.

5.2.4 LRIA RESULTS

Two hundred thirty two (232) persons' retinal reflex images were analyzed with the LRIA. One hundred thirty two (132) were of students from ASD, and one hundred (100) were persons from Dr. S. H. Hay's private practice. The accuracy of the LRIA was sixty seven (67) percent. Table 5.1 lists a summary of the results.

While the LRIA could process a person's retinal reflexes in one minute, the lack of pattern information reduced the accuracy of the analyzer to a point where it is unacceptable for use in ocular screening.

5.2.5 TRAINED OBSERVER RESULTS

The same person's retinal reflex images which were evaluated by the LRIA were evaluated by trained observers. Dr. S. H. Hay was able to visually inspect the retinal reflex images at a rate of five to seven per minute and obtain an accuracy of ninety (90) percent. Other observers trained by Dr. Hay acheived an accuracy from eighty (80) to ninety (90) percent. Table 5.2 lists a summary of the trained observers results.

LRIA RESULTS

Table 5.1

| | |
|---|-----|
| Number of persons' reflexes evaluated | 232 |
| Number of correct evaluations | 154 |
| Number of incorrect evaluations | 78 |
| Number of false positives | 51 |
| Number of false negatives | 27 |
| Accuracy percentage | 67 |

TRAINED OBSERVER RESULTS

Table 5.2

| | |
|---|-----|
| Number of person's reflexes evaluated | 232 |
| Number of correct evaluations | 208 |
| Number of incorrect evaluations | 24 |
| Number of false positives | 8 |
| Number of false negatives | 16 |
| Accuracy percentage | 90 |

DEFINITIONS:

False positive — Based upon the retinal reflex examination, the person's eyes are adjudged to be optically equal; however the person's eyes were found to be optically unequal when examined by medical practitioners.

False negative — Based upon the retinal reflex examinations, the person's eyes are adjudged to be optically unequal; however the person's eyes were found to be optically equal when examined by medical practitioners.

6.0 SUMMARY

A new ocular screening system and procedure have been developed and successfully demonstrated. Data acquisition is accomplished with remote sensing photographic techniques that are easily mastered by non-skilled personnel. Objective data is acquired in a non-invasive manner which is completely safe for the person being examined. Prior to being photographed, a person is placed in a semi-dark room for a period of five to ten minutes to allow time for their eyes to dilate naturally. After the waiting period, the only cooperation required from the person being photographed is that they fixate their eyes on a strategically located blinking light emitting diode while their generated retinal reflexes are being photographed.

In addition to generated retinal reflex information, the data acquisition sensor's images contain information which identifies the person, and shows the color of the person's eyes. A data base of 232 person's generated retinal reflex images was compiled during this contract period. Based solely upon information contained in these images, a trained observer was able to state wheather a person had normal or abnormal eyesight in ninety (90) percent of the cases. The observer was absolutely correct in identifying persons who were nearsighted or farsighted. If the abnormality was caused by other disease processes, then the observer could only speculate about the cause of abnormality.

When the observer's results were compared with the person's medical examination results; the observer had 3.4 percent error in the cases that were identified as normal, and an error of 6.9 percent in the cases that were identified as abnormal.

APPENDIX A

LRIA DESCRIPTION

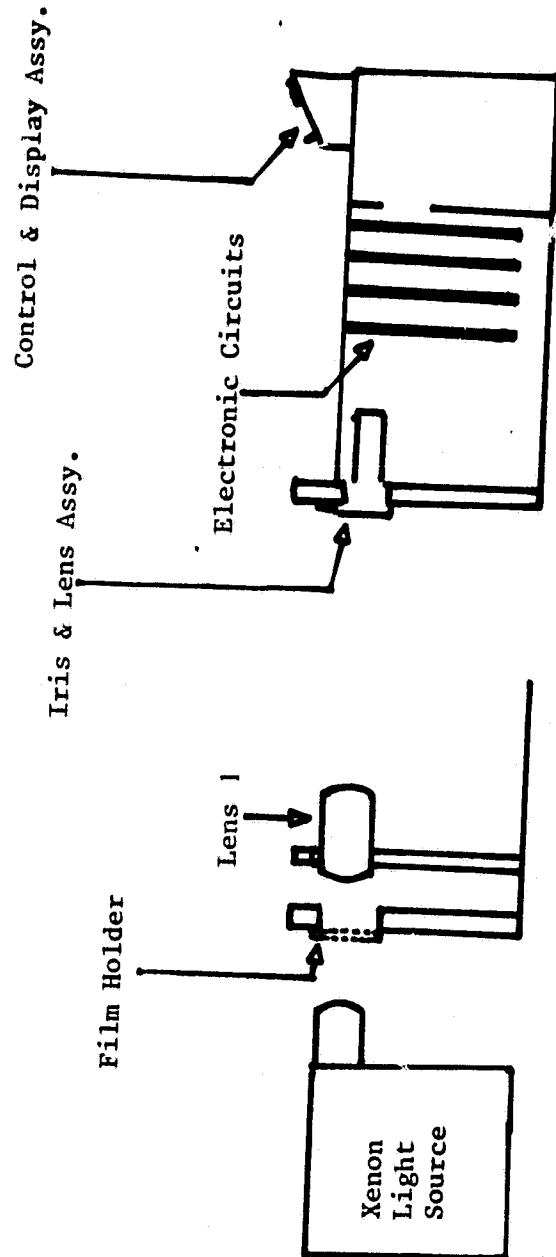
The LRIA is an electro-optical analog image analyzer which compares the total intensity of one eye's retinal reflex image with the total intensity of the fellow eye's retinal reflex image. It was designed to process one set of retinal reflex images per minute.

Figure 1 illustrates the analyzer in block diagram form. A xenon light source is focused to illuminate a 35 millimeter transparency which contains retinal reflex images. Lens 1 projects and focuses the transparency's image in a plane which contains a pair of variable aperture irises. The irises are adjusted to block all information except the retinal reflex images. A lens system, located six focal lengths behind each iris, projects and focuses the light intensity on the face of a photoconductor. This projected light incident on each photoconductor represents the retinal reflex image intensity.

The output from each photodetector is amplified, and routed to separate eight (8) bit analog to digital (A/D) converters as shown in figure 2. The eight bit digital data is conditioned and processed by circuits shown on the schematic in figure 3.

The digital output is used to drive three $3\frac{1}{2}$ digit light emitting diode displays. As shown in figure 3.4, quantized level of the left eye's and right eye's retinal reflex intensity is displayed. The difference between the intensity of the retinal reflexes is also displayed.

Figure A1 LRIA BLOCK DIAGRAM



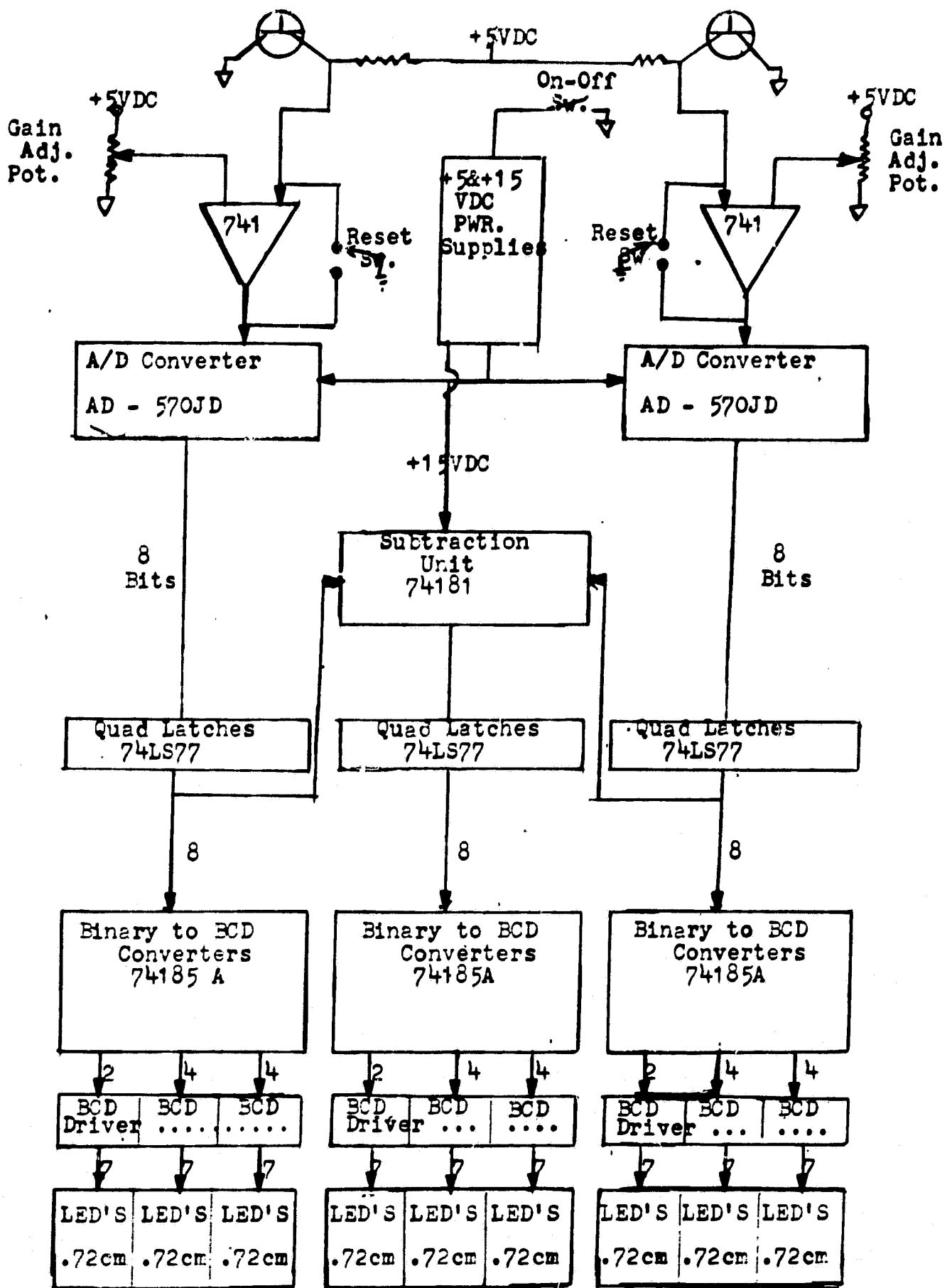


Figure A2 LRIA ELECTRONICS BLOCK DIAGRAM

ORIGINAL PAGE IS
OF POOR QUALITY

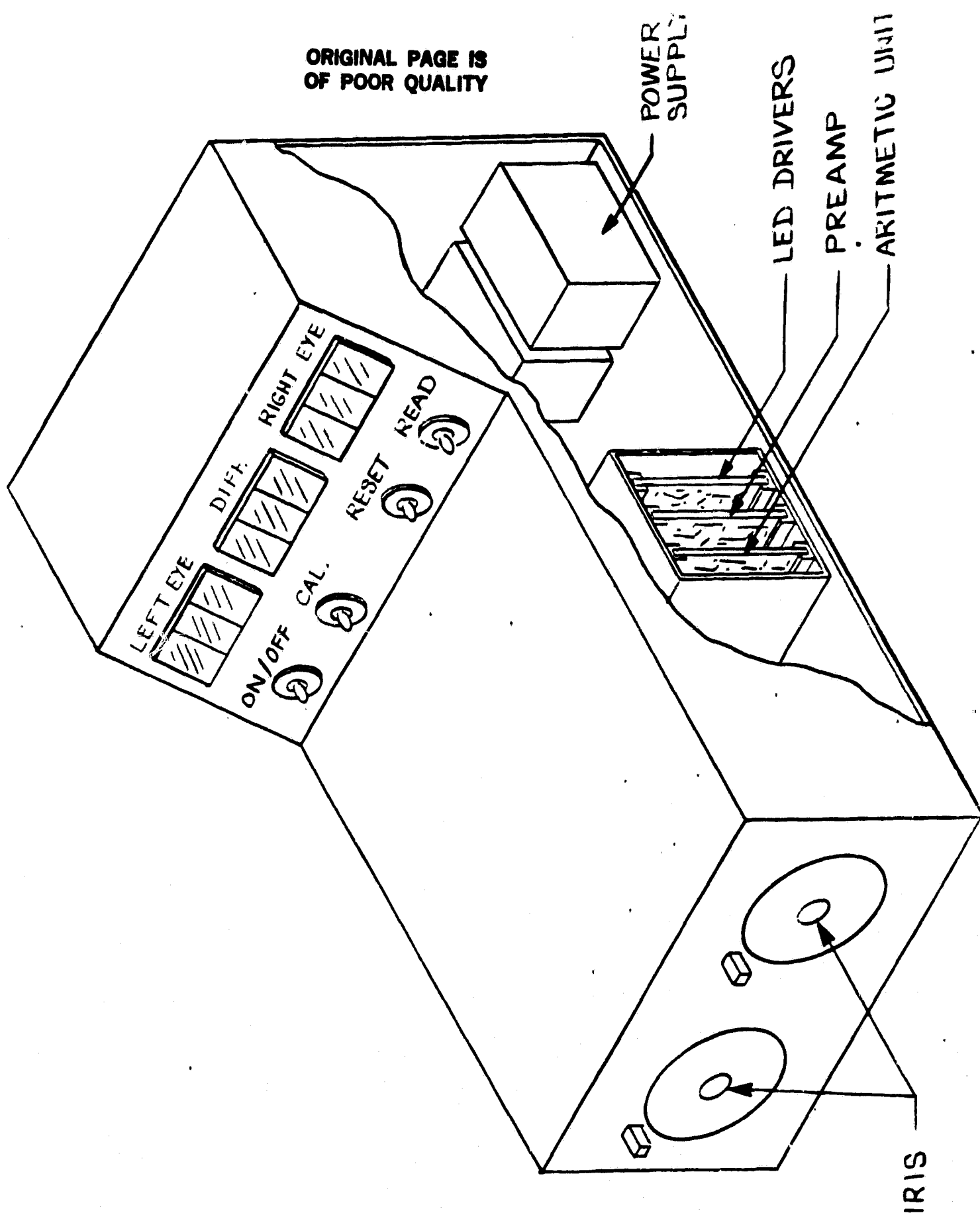


Figure A4 ISOMETRIC OF LRIA DATA PROCESSOR

APPENDIX B

**RETINAL REFLEX PHOTOMETRY IN THE DETERMINATION
OF AMBLYOPIC AND PRE-AMBLYOPIC STATES
IN CHILDREN**

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**Prepared for and presented Southern Medical Association Meeting
New Orleans, Louisiana, 1981**

Abstract:

Vision is a complex physical and neurologic process in which the optical nature of the eyes plays a critical role. A defect in this part of the visual axis will limit the efficacy of the whole. This modulating function is of greatest effect during the early years of childhood when the visual centers of the brain are immature and very plastic. Aberration in the physical structure or alignment of the eyes may produce pathologic neurocompensatory changes in the brain which left unattended become irreversible. Two common examples of this abnormal state are accommodative esotropia and amblyopia. Both have a large optical component in their etiologies and in most cases are corrected by optical methods.

Generated retinal reflex photometry is a screening method that has demonstrated an ability to detect optical defects in the eyes of children. It is these same defects that tend to be the antecedents of the more serious pathologic neurocompensatory processes. Detection of these pathologic antecedents at an early age permit more effective management and treatment of amblyopia.

This technique is fast, safe, inexpensive and provides a permanent record. It requires no response from the subject but does require a modicum of cooperation. It is attractive as an ocular screening method because it does not require highly trained personnel to administer the examination, yet would appear to yield good accuracy.

The data obtained by this method lends itself to mechanized optical processing. This capacity has been explored in this study. Presently two techniques can be utilized but are inferior to the interpretation of a trained observer in reading the retinal reflexes. Additional technologic advances might mechanize this technique more completely.

RETINAL REFLEX PHOTOMETRY IN THE DETERMINATION
OF AMBLYOPIC AND PRE-AMBLYOPIC STATES
IN CHILDREN

Introduction:

Amblyopia is very responsive to preventive medical attention. Visual loss from this disease can be prevented in the vast majority of patients if the condition is detected and treated at an early stage. The etiologic cause for amblyopia is still nebulous but there is a strong clinical coincidence of association with form vision deprivation and abnormal binocular interaction. Such conditions as strabismus, anisometropia and medial opacification fall into this category and are optical abnormalities of the individual's visual system. Clinical and experimental work confirms the impression that if these optical abnormalities or inequalities between the eyes are of significant degree during the period in which the child is visually immature, a neurocompensatory process may develop into the pathologic state of amblyopia.

Pathophysiology:

Recent work performed by Hubel and Wiesel on cats and von Noorden on monkeys would tend to indicate that the amblyopic pathophysiology is reflected primarily in alterations of the lateral geniculate body, as well as in the occipital lobe of these various species.^{1,2,4,5}

Investigation using sub-species indicates that the pathologic process is reversible if the optical inequality is corrected before the age of visual maturity is approached.¹ After

visual maturity has been reached, a physical alteration of the central nervous system has developed that cannot be reversed.¹

Simultaneous bilateral and optically equal images must be produced on each foveola to prevent maldevelopment of binocular cells in the cerebral cortex and cells in the lateral geniculate body on the involved side. This must occur within the first weeks of life.^{1,2,3,4,8}

Treatment in Man:

Success in treating amblyopia in man is seldom accomplished after the age of 7 or 8 years. The treatment of amblyopia consists of providing each eye with essentially the same visual input and of enforcing equal utilization of the eyes. This is accomplished by the correction of refractive error through spectacles, by patching, or more rarely, by surgical procedures such as the removal of a cataractous lens or the correction of a ptotic lid. The limiting factor in successful management of amblyopia is primarily age and not expense.

Present Concept of Screening:

Ophthalmologists and Pediatricians have approached the problem of amblyopia somewhat ineffectively and at times with great expense.^{9,10,14} Presently amblyopia is suspected in non-communicative children with an ocular misalignment or who demonstrate a change in behavior pattern when one eye is occluded.

This type of determination requires personnel skilled in ocular manifestations of sensory motor anomalies. As a child

approaches the age of visual maturity he is able to give an explicit verbalization indicating that one eye does not see clearly. Until a child reaches this level of maturity it is difficult to diagnose and therefore treat amblyopia effectively.

A host of screening devices for those children in the age group three to seven have been designed to determine visual acuity. The more commonly used devices are the E chart and Allen cards. More recent developments include such devices as the random dot stereoscopic vision testing devices.^{15,16} The unifying theme in these screening techniques is that they require a subjective response from the child. The younger the child, the less accurate is the response.

Photographic Studies:

Two methods of using photography have been described in an attempt to evaluate visual defects in children. A photo-refraction technique described by Howland¹⁷ has been used to detect astigmatic refractive errors. More recent studies by Kaakinen¹⁸ and Kaakinen and Tommila¹⁹ report a study in which 82% of strabismus cases and 100% of children with orthophoric anisometropias of 3.0 diopters or more were detected.

Incidence of Amblyopia:

From two to four percent of the population suffers with amblyopia to some degree.^{11,12} The incidence of amblyopia reported increases in proportion to the age of the children examined which certainly suggests a difficulty in detecting amblyopia in younger children.¹⁰

Retinal Reflexes:

Retinoscopy, a technique long practiced by ophthalmologists, gives an objective appraisal of the refractive power of the eyes. A recent publication indicates that retinal reflex comparison of an individual's eyes is an effective method for determining a host of conditions, one of which is optical inequality.¹³ While the study of the comparison of retinal reflexes obtained by the use of an ophthalmoscope is unable to reveal the degree or the type of inequality in the refractive state between the eyes, it nevertheless does indicate a difference.

It has become apparent that these differences can be enhanced by simple photographic procedures to provide a rapid screening method for children. The ability to take a picture and to determine a difference in the optical quality of the retinal reflexes is the only skill that is required. This approach also provides a permanent record for later comparison.

Introduction to Retinal Reflex Photometry in Ocular Screening:

Amblyopia is a neuropathologic state. A response from the patient being tested indicating abnormal vision is required to make this diagnosis. This requirement makes any screening procedure for amblyopia difficult and expensive.

A correlation exists between amblyopia and certain ocular antecedents of this disease (strabismus, anisometropia). By using optical measurements that detect the correlates of amblyopia it is possible to screen for the disease itself, as well as other abnormal ocular states in humans.

Retinal Reflex Photometry:

Retinal reflex photometry is a method for recording the image of the retinal reflex from a patient's eyes under simple but special conditions. The process is completely noninvasive and the results depend solely on the analysis of the recorded image. The photograph of the retinal reflex is analyzed by quantifying the intensity, spectra and optical patterns of the reflex and by comparing them with the same characteristics of the fellow eye and an idealized normal eye. Careful analysis of the retinal reflex not only isolates pre-amblyopic conditions but it may also detect a variety of pathological conditions of the optical ocular visual system.

Photometer:

The photometer is a camera which directs an illuminating light flash in the same optical plane as the plane used by the camera lens to focus the image. (Fig.1) The illuminating flash is a standardized light source which has a level of intensity of illumination over the full visible light spectrum. The flash is mounted immediately below the lens of the camera. The lens is a 1000 mm. F11 Cassegrain telescope which is focused at 18.9 feet. The film used in this study was ASA 400 Ektachrome which was developed and processed commercially.

The camera lens produces a very shallow depth of field so that the subject's head must be stabilized at 18.9 feet by an optical hood. Critical care is necessary in alignment of X, Y and Z axes of the subject to prevent the introduction of optical aberration into the photograph of the subject's retinal reflexes. The field of view recorded by the camera includes both eyes and patient identification number.

A red blinking LED was placed immediately above the lens and the child was then requested to fixate the LED - proper cooperation was monitored by a sighting scope that illuminated the eyes and generated a weak retinal reflex that was apparent to the photographer. The ambient light was reduced to an absolute minimum to produce normal pupillary dilation.

These retinal reflexes recorded on film represent the patient's eyes optically processing a uniform and quantized amount of light simultaneously presented to both eyes over a period of about 1/100 of a second. Any difference in the retinal reflexes between the two eyes is a manifestation of some optical difference in the eyes. It is the optical configuration of the eyes that determines the quality of the images on the retina and thereby limits the quality of visual acuity. (Deductive reasoning then implies all of the subsequent corollaries; i.e. (1) eyes out of focus do not see well without spectacles, (2) cataracts produce poor vision, etc.)

Population Studied:

112 subjects were sequentially selected from my private practice. These were children from six months to thirteen years of age and were photographed as they presented for ophthalmic examination over a period of 3.5 months. Many of these children were referred by other physicians or school testing programs having failed some form of vision screening examination. A very large majority of these children would appear to be from the mid to upper socioeconomic families. Racial distribution was 98 white and fourteen black or Asian.

These children's eyes were photographed with an identifying code number and the data was collected via this number. The coded retinal reflex was analyzed for ocular disease and subsequently the coded results compared to the patient's ophthalmic status.

Ophthalmic Examination:

A complete ophthalmic examination was performed which included visual acuity of each eye with and without best correction; cycloplegic refraction; appraisal of ocular alignment; examination of the anterior segment with a slit lamp and indirect retinoscopy.

Photometric Analysis:

These photographs were projected on a screen and analyzed by a trained observer. Color, intensity, equality and pattern were considered. Using this method of analysis it was possible to detect refractive errors from 1.5 diopter of positive or minus sphere and of spherical equivalents to 0.5 diopter. Minus spheres or spherical equivalents were detected by a bright band inferiorly on the reflex and positive spheres or spherical equivalents by a bright band at the top of the reflex. The degree of refractive error could be quantized to some extent by the size of intensity of the bright band. The larger refractive errors were noted to have larger, more intense bands.

Orthophoric anisometropia and heterotropia were detected by intensity differences and spectral shifts of the retinal reflexes in one eye compared to the other. Small angles of esotropia with normal or near normal refractive errors were most difficult to detect or were missed.

Seven children examined were photographic failures. These occurred in the very young children or mentally retarded and were due to closed eyes or poor cooperation. Five photographs were not returned by the commercial processor.

Test Results:

100 photographs were analyzed. This group consisted of 82 abnormal and 13 normal children. Analysis using this technique was accurate in detecting ocular abnormality in 90%. The incorrect determination consisted of 4 false positives and 6 false negatives.

There were twenty-five cases (22%) of amblyopia in the series studied. Four of these were photographic failures (either the eyes were closed or film was not returned). The remaining twenty-one cases were analyzed by the trained observer method. From this group the technique was seen to be 81% correct in detecting amblyopia. The incorrect determinations comprised four cases or 19% of the total; of these four cases, two were strabismic amblyopias that had been surgically corrected and were now small angle esotropias with essentially normal refractive errors. One additional failure was an accommodative esotropia with amblyopia that had been treated by spectacle correction. At the time of the photograph, the eyes were perfectly aligned but the child continued to have a residual amblyopia.

Digital Image Computation and Processing:

For digital computation the data was acquired in the form of 30 mm. slides, which were digitized using spot sizes of 17.5, 35, 70 and 140 microns and integration times of 40, 80, 160, and 320 milliseconds. The digitized data was read directly

onto computer disks and displayed on a black and white television monitor for analysis. The analysis performed consisted of selecting a rectangular subportion of the image for histogramming, plotting and recording the intensity values as they occur in the image. Examination of spatial and spectral intensity variations and comparing the relative integrated reflex intensities of the left eye to the right was performed.

While the digitization of these retinal reflexes was readily accomplished and optical aberration of the eyes identified, no significant advantage was determined in using this method. It was slower, less accurate and more expensive than the determination of a trained observer.

An additional method of digitized image processing was performed using spectral analysis. The spacial location of each point in the retinal reflex was computed using a red, green and blue filter. Each locus was expressed as a three dimensional vector whose components were represented by red, green and blue intensity values. These values were then plotted, using a red-green axes and a red-blue axes. The analysis of these data demonstrated that the linear perspective of red, green and blue were interdependent. This method could not demonstrate an optical difference between eyes. However, a marked racial characteristic was detectable between white and nonwhite children. This presumably reflected the increased amount of choroidal pigmentation present in colored as opposed to white children.

Analytic Image Computation and Processing:

Analytic computation was performed on these data using a low resolution image processor. This instrument optically excluded all data from the photographs except the retinal

reflexes. The reflexes were then analyzed by integrating their intensity over the area of the reflex. This produced a value for each reflex that was then compared to an empirical "normal" reference value for computational purposes. If the value obtained from the left or right eye for a patient's reflex was significantly different from this "normal" reference value, the eye was considered abnormal. This technique was quite successful in the detection of pathologic states due to refractive errors of 2.50 diopters or greater or ocular misalignments of greater than 20 diopters. The sensitivity of this instrument was poor for conditions less than this and for that reason had an unacceptable false negative rate making it unsuitable for screening.

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The author acknowledges the help and financial assistance for this work from:

1. National Aeronautics and Space Administration
George C. Marshall Space Flight Center
John Richardson, Office of Technology Utilization
Contract NAS8-33819
Huntsville, Alabama
2. Arthur Jampolsky, M.D., Director
Smith-Kettlewell Institute of Visual Sciences
San Francisco, California